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AN ASSESSMENT OF WATER QUALITY IN THE CLARK FORK RIVER AND ITS MAJOR TRIBUTARIES, BASED ON THE STRUCTURE AND COMPOSITION OF SUMMER ALGAE ASSOCIATIONS IN THE PERIPHYTON COMMUNITY

ERICH E. WEBER

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SUMMARY

Periphyton (benthic algae) samples were collected by the Montana Department of Health and Environmental Sciences from natural substrates at locations on the Clark Fork River and selected tributaries; samples were collected at 24 stations in August 1989 and 25 stations in August 1990. Samples were analyzed for relative abundance of non-diatom genera, relative abundance of diatom species, number of diatom species, diatom species diversity, and relative abundance of diatom species in three pollution-tolerance groups.

The algae indicated very poor water quality and severe use impairment in Silver Bow Creek during both years. Heavy metals above the Butte WWTP and both metals and excess nutrients below the WWTP were responsible for the pollution. The Mill-Willow Bypass also had very poor water quality during both years.

Moderate pollution and use impairment were indicated in the ACM Pond 2 discharge, Warm Springs Creek, and at Clark Fork River sites above the Little Blackfoot River in 1989, with some improvement noted in 1990.

Water quality at Clark Fork River sites from Gold Creek to above Missoula, in the Blackfoot River, and in the Bitterroot River was only slightly impaired during both years, based on the structure and composition of algae associations at these sites.

Slight-to-moderate use impairment and water pollution was indicated downstream of the Missoula WWTP and Stone Container discharges during both years. Gradual improvement of water quality was indicated by the algae associations in the Clark Fork River from Alberton to the Flathead River during both 1989 and 1990.

PREFACE

This report is submitted to the Montana Department of Health and Environmental Sciences (DHES) in fulfillment of the conditions agreed upon in DHES contract number 210001, dated June 13, 1990. The author is solely responsible for all taxonomic identifications and data interpretations contained herein.

Many thanks to my mother-in-law, Margaret Poor for volunteering many hours of invaluable assistance with data and word processing; to my parents, Lou and Ed Weber for giving freely and frequently of their time to provide quality childcare; and to my wife, Anne Weber for her continuous encouragement and assistance.

Thanks also to John Jarvie of the Natural Resource Information System and Gary Ingman of the Water Quality Bureau for making available the excellent map of the Clark Fork Basin Monitoring Project.

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INTRODUCTION

In August 1989 and August 1990, the Water Quality Bureau of the Montana Department of Health and Environmental Sciences (DHES) conducted benthic algae surveys on the Clark Fork River and selected tributaries as part of the Clark Fork Basin Monitoring Project. This report describes the results of the analysis of periphyton samples from these surveys, which was performed under contract to DHES. This report also interprets these data to assess the water quality at the stream sites surveyed. Results of similar surveys conducted annually since 1986 were described in reports prepared by DHES (Bahls, 1987 and 1989).

Periphyton is the assemblage of small, often microscopic organisms (invertebrates, bacteria, fungi, and benthic algae) that live attached to or in close association with the surface of submerged substrates. Benthic algae typically predominate the periphyton community. They can be conveniently divided into two major groups: the diatoms and the non-diatoms, based on the presence or absence of a rigid siliceous cell wall. Both groups can be used to assess water quality; however, due to the unique characteristics of the cell walls, diatoms are readily identifiable to species while it is generally impractical to identify non-diatom algae below the genus level. Algae are useful as biomonitors of water quality because they occur in very large numbers, are highly sensitive to physical and chemical factors, and have known environmental requirements and pollution tolerance unique to individual species (Bahls, 1989).

Ideally, the algae present in a periphyton sample should reflect the environmental conditions that exist at a particular stream location for up to several weeks prior to sample collection. However, in addition to water quality, many factors such as substrate scour, recolonization rates, seasonal succession, and sloughing can affect the types and amount of algae present at a given time. By allowing adequate time for substrate recolonization following spring runoff, by sampling before sloughing of algal biomass occurs in late summer, and by sampling at roughly the same time each year, the effects of factors unrelated to water quality are minimized. Monitoring conducted during the first half of August probably meets the aforementioned criteria. Additionally, it very likely encompasses the period of poorest seasonal water quality and maximum environmental stress on stream biota due to low streamflow, high water temperature, and minimum wastewater dilution.

METHODS

Composite periphyton samples were collected by DHES personnel in 1989 and 1990 from natural substrates at established monitoring stations on the Clark Fork River and selected tributaries. Samples were collected at 24 stations from August 15 through 18 in 1989 and 25 stations from August 5 through 9 in 1990 (Table 1 and Figure 1). Samples were collected according to procedure 6.2.2 (Periphyton) in the Water Quality Bureau's Field Procedure Manual (WQB, 1989).

Each sample was processed by this contractor as follows: Solf-bodied (non-diatom) algae were identified to genus under a light microscope at 100X and 400X. The relative abundance of each genus was estimated by cell numbers, based on microscopic examination.

Samples were then processed in concentrated sulfuric acid and potassium dicromate to oxidize the soft-bodied algae and organic components of the diatoms, leaving behind the siliceous cell walls (frustules) of diatoms and other inorganic matter. This "cleaned" material was then mounted on glass slides in Hyrax medium for diatom analysis. Cleaning and mounting was performed by DHES personnel as stipulated under this contract.

Each mounted diatom sample was first scanned under 1000X (oil immersion) and a species list was prepared. Approximately 375 to 450 diatom frustules were then counted at random in each sample, and the percent relative abundance of each species was calculated. For each diatom association the total number of species identified, number of species counted (species richness) and Shannon diversity were calculated. Also calculated were the number and total percent relative abundance of diatom species in the three polution tolerance groups of Lange-Bertalot (1979).

Table 1. Periphyton sampling locations on the Clark Fork River and Tributaries, 1989 and 1990.

STATION	SITE DESCRIPTION
00	Silver Bow Creek (SBC) above Butte Wastewater Treatment Plant
01	SBC below Colorado Tailings
02	SBC near Ramsey
03	SBC at Frontage Road above Warm Springs (ACM) Ponds
04	ACM Pond 2 Discharge (Silver Bow Creek)
05	Mill–Willow Bypass near mouth
06	Warm Springs Creek near mouth
07	Clark Fork River (CFR) below Warm Springs Creek
08	CFR near Dempsey
8.5*	CFR at Sager Lane
09	CFR at Deer Lodge
10	CFR above Little Blackfoot River
11	CFR at Gold Creek
12	CFR at Bonita
13	CFR at Turah
14	Blackfoot River near mouth
15.5	CFR above Missoula
18	CFR at Shuffield's
19	Bitterroot River near mouth
20	CFR at Harper Bridge
22	CFR at Huson
23	CFR near Alberton
24	CFR at Superior
25	CFR above Flathead River
27	CFR above Thompson Falls Reservoir

*New location in 1990

Figure 1.
Clark Fork Basin
Monitoring Project

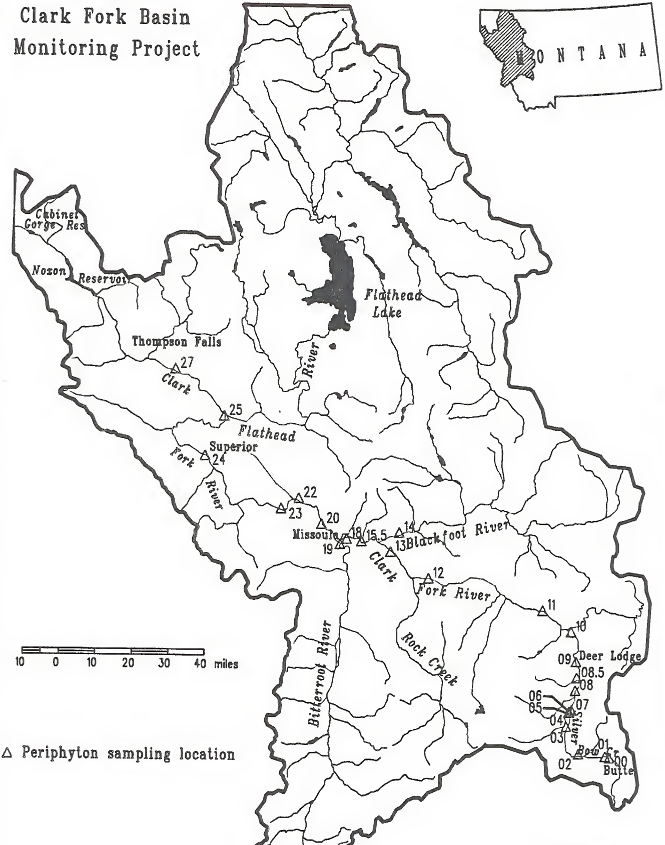

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Table 2. Estimated relative abundance of diatoms and genera of other algae in periphyton samples collected from the Clark Fork River and tributaries, August 15–18, 1989. R=rare; C=common; VC=very common; A=abundant; VA=very abundant

ALGAE	STATION																							
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
CHLOROPHYTA (green algae)																								
Ankistrodesmus sp.	C	R					R		C	R						R		VC		C	VC	VC	VC	
Chaetophora sp.															A				A		C	VC	C	VC
Cladophora sp.					C	C	VC	C	C	VC	A	A	A	A	VC		VC	VC	C	R	VC	VC	A	A
Closterium sp.							C				R	R	R	R	R	C		C	R	C	C	C	R	R
Coelastrum sp.					R				R									C	R	C	R	R	C	
Cosmarium sp.				A	VC	C		C	VC	R		R			C	VC	VC	C	VC	VC	VC	VC	VC	VC
Cylindrocapsa sp.															VC	VC	VC		R		R	R	R	
Enteromorpha sp.									C	C														
Gloeocystis sp.	C	C	VC																		R		R	
Microspora sp.	VA																							
Mougeotia sp.						R																		
Oedogonium sp.						C				R												R		
Oocystis sp.																		R				R		
Palmella sp.					R	R			R	R											R			
Pediastrum sp.					VC	R	R	C	VC	R						C		R	R	R	C	R	C	C
Scenedesmus sp.	R	R	C	A	C	C	R	R	A	C		R		R	R	C	R	A	C	VC	VC	VC	VC	VC
Sphaerocystis sp.																		R	R		R			
Spirogyra sp.												R		A										
Staurastrum sp.					R										R			R		R				
Stigeoclonium sp.	R	VA	VA	R	VA	VC		VC	C	VC	VC	R	VC	R	R	R	VC	R	C	A	VC	C	C	R
Ulothrix sp.						R									R	R								
Zygnema sp.														R										
EUGLENOPHYTA (euglenoid algae)																								
Euglena sp.		R																						
CHRYSOPHYTA (yellow-green algae)																								
Vaucheria sp.							R				C													
BACILLARIOPHYTA (diatoms)	A	VC	VC	C	A	VA	VA	VA	VA	VA	VA	A	VA	VA	A	A	VA	VA	VA	VA	VA	VA	VA	VA
CYANOPHYTA (blue-green algae)																								
Calothrix sp.																	R					C	R	C
Chamaesiphon sp.																C								
Coelosphaerium sp.																								R
Dactylococcopsis sp.																				R	R			
Dichothrix sp.												C	VC		R									C
Lyngbya sp.																								R
Microchaete sp.													C	VC		C								
Nostoc sp.							A	A	VA	A	C	VC	VC	A	A	R								
Oscillatoria sp.	R	R		C	C	R		C	VC	A	C	C		C	C		C	VA	R	A	C	VA	A	A
Phormidium sp.	R				C	R	C	VC	A	VA	VC	VC	C	VC	A	A	A	VC	C	VC	R	C	A	A
Rivularia sp.												C	C		C	VC	C				C	A	VC	A
Synechocystis sp.	VC	C	A	VA		R																		
RHODOPHYTA (red algae)																								
Audouinella sp.											R	C	VC	VC	A	VA					R	R	VC	
PHAEOPHYTA (brown algae)																								
Heribaudiella sp.															VC									
TOTAL NON-DIATOM GENERA	8	7	4	5	10	12	8	8	12	12	8	12	9	11	16	14	9	13	12	12	18	17	16	14

Table 3. Estimated relative abundance of diatoms and genera of other algae in periphyton samples collected from the Clark Fork River and tributaries, August 5–9, 1990. R=rare; C=common; VC=very common; A=abundant; VA=very abundant

ALGAE	STATION																								
	00	01	02	03	04	05	06	07	08	8.5	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
CHLOROPHYTA (green algae)																									
Ankistrodesmus sp.	C	C	R			C	R	R	C	VC	C	R	C						A	C	C	C	C	C	C
Chaetophora sp.																A							R	A	VC
Cladophora sp.					C		VC	C	C	VC	VC	A	A	A	A	R	A	A	VC	A	VC	VC	A	A	C
Closterium sp.					C		C	C						R	C		R	R	C	C	C	C	R	R	C
Coelastrum sp.						C				C									C		R	R	R	R	R
Cosmarium sp.	R			R	C	C		C	R	C	R		C		R		C	C	VC	VC	VC	VC	C	C	VC
Cylindrocapsa sp.																R	C	R					R	C	
Enteromorpha sp.											C	C			VC										
Gloeocystis sp.	A	C	C	C	R	C	R												R		R				
Gongrosira sp.														R			VC	R							R
Microspora sp.	VC			VC																					
Mougeotia sp.						C																			
Oedogonium sp.							VC	A	VC	A		VC		C					R						
Oocystis sp.																									
Palmella sp.		VC	VC	VC																					
Pediastrum sp.					C	R		R	C	C	C	R	R						C		R	R	R		R
Scenedesmus sp.	R	R	C	A	C	VC		C	C	C	C	C	C	C			C	VC	VC	VC	VC	VC	C	C	VC
Sphaerocystis sp.																			C						
Spirogyra sp.							R																		
Staurastrum sp.					R	R		R											VC	R	C	R			
Stigeoclonium sp.	R	VA	A	C	VC	R	C		R	R	R	R	R		C	C	R	VC	C	VA	A	R	R	C	C
Ulothrix sp.							C									R			R	R	R				
CHRYSOPHYTA (yellow–green algae)																									
Tribonema sp.	C	R				R																			
Vaucheria sp.							R		VC	R	A	R													
BACILLARIOPHYTA (diatoms)	A	VC	VC	C	A	VA	VA	VA	A	VA	A	A	A	VA	A	A	A	VA	VA	VA	VA	VA	A	VA	VA
CYANOPHYTA (blue–green algae)																									
Anabaena sp.					VC								R												
Calothrix sp.													C			VC	R	C				R			R
Chamaesiphon sp.											C	VC			VA			A							
Dichothrix sp.																C	C								R
Lyngbya sp.					R																				
Merismopedia sp.						R																			
Microchaete sp.														C	C										
Nostoc sp.									A	A		VC	VA	A			VC	R					C		
Oscillatoria sp.				R	A	R	VA		R				R	R		R	R	VC	A		C	C	VC	VC	C
Phormidium sp.					VA	C	VC		C	VA	C	C	VC	A	A		VA	A	A	A	VA	VA	VA	VA	VC
Rivularia sp.					C									VC	VC	VA	VC	VC			C	A	VA	A	A
Synechocystis sp.	VA	A	A	VA																					
Tolypothrix sp.																							R		
RHODOPHYTA (red algae)																									
Audouinella sp.						R	C			R		C		VC	C	R	VC	C			R		C	VC	C
Lemanea sp.																	C								
TOTAL NON–DIATOM GENERA	8	7	6	8	13	14	12	8	11	12	10	12	11	11	10	10	15	14	15	9	15	13	16	13	16

RESULTS AND DISCUSSION

Non-Diatom Algae

The estimated relative abundance of diatoms and non-diatom algae for 1989 and 1990 are presented in Tables 2 and 3, respectively. Diatoms, green algae, and blue-green algae were the dominant groups at all sites, although their relative abundance varied from site to site. Diatoms were common or greater at all sites and are discussed in detail in a later section.

Figures 2 and 3 show the number of genera of green, blue-green, and other non-diatom algae (euglenoid, yellow-green, red, and brown) that were common or greater in estimated relative abundance at each site. Genera estimated as rare were not included because the significance of these very small populations was judged to be minimal. During both 1989 and 1990, at least one genus of green algae was found at each site, and all but two sites had at least one genus of blue-green algae that was common or greater. Only one genus of the "other" group, the red alga *Audouinella*, was found to be common or greater at several sites. Euglenoid, yellow-green, and brown algae were relatively unimportant components of the benthic algae. In general, numbers of genera of non-diatom algae increased from upstream to downstream in both 1989 and 1990.

In 1989, the fewest numbers of genera were found at the four Silver Bow Creek sites (00-03), where only pollution tolerant green and blue-green genera were present. Nearly twice as many genera were seen at ACM Pond 2 discharge (site 04) than at sites above the Warm Springs treatment ponds. The increase in genera, plus the appearance of forms more sensitive to pollution, indicate an improvement in water quality below the ponds. In comparison to 1989, the 1990 results from all Silver Bow Creek sites showed an increase in numbers of genera, especially at sites 01 and 03, where the number of green algae genera at least doubled. There was also an increase in the number of genera seen at site 04 in 1990. Additionally, the number of genera of blue-green algae was markedly higher at site 04 compared to all Silver Bow Creek sites upstream; however one genus (Anabaena) was a planktonic form probably flushed from the Warms Springs pond system.

Figures 2 and 3. Number of non–diatom algal genera common or greater in estimated relative abundance in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.

Figure 2. August 15–18, 1989.

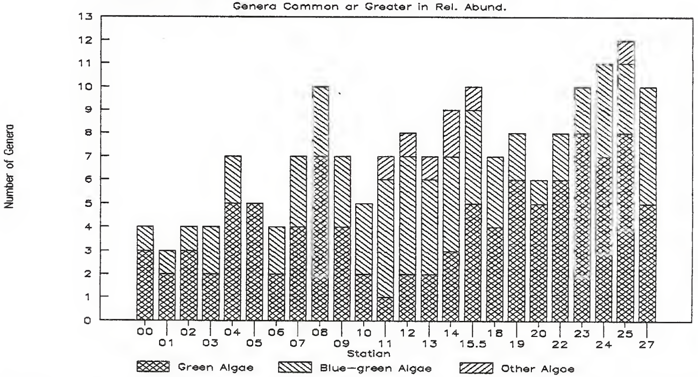
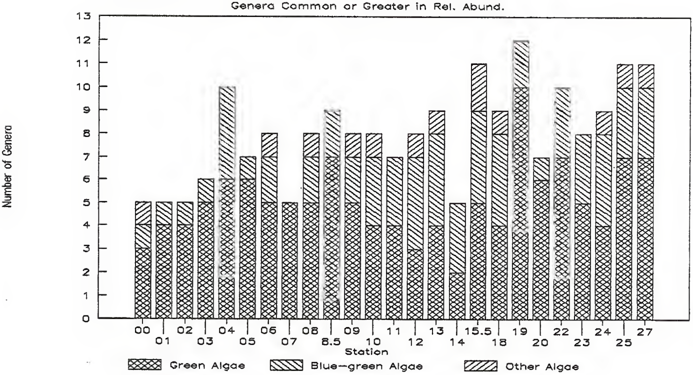


Figure 3. August 5–9, 1990



In 1989, pollution tolerant forms were dominant in the Mill-Willow Bypass (site 05). Genera found at Warm Springs Creek (site 06) were comparable in number to those seen in Silver Bow Creek, but consisted of forms more sensitive to pollution. In 1990, somewhat less-tolerant forms were dominant at site 05, and genera at both sites 05 and 06 increased in number and diversity, suggesting some improvement in water quality in both tributaries.

In 1989, the number of green algae genera at upper Clark Fork River sites decreased steadily from a high of seven near Dempsey (site 08) to only one at Gold Creek (site 11), and remained low as far downstream as Turah (site 13). The number of blue-green genera, however, remained fairly constant or increased at all mainstem sites between Warm Spring Creek and the Blackfoot River. The same general trend was seen in 1990. These changes may have been due, at least in part, to a relative nitrogen deficiency (inorganic nitrogen to ortho phosphate ratio of less than 2) typically seen in the Clark Fork River between Deer Lodge and Turah, and the ability of some of the common blue-green algae (Nostoc and Rivularia) to fix nitrogen (Bahls, 1989).

The number of genera in the Blackfoot River (site 14) in 1989 was similar to that of adjacent Clark Fork River sites. A dramatic decrease occurred in 1990 in the total number of genera at site 14 compared to 1989. While this was possibly due to sampling error or sample decomposition (personal observation), environmental factors may have also played a role. The number of genera above Missoula (site 15.5) were at or near the maximum seen in the upper Clark Fork River during both 1989 and 1990. This suggests that the Blackfoot River had a positive effect on water quality in the Clark Fork River.

The effluent from the Missoula WWTP had a significant negative impact on the water quality in the Clark Fork River, based on a decrease in the number of genera and an increase in pollution tolerant forms at Shuffield's (site 18) compared to site 15.5 in both 1989 and 1990.

During both years and especially in 1990, there were higher numbers of green algae genera, but fewer blue-green genera in the Bitterroot River (site 19) compared to the Clark Fork River above their confluence. This suggests higher water quality in the Bitterroot River, although different water chemistry also may have been a contibuting factor.

The Bitterroot River may have influenced the relative numbers of green and blue-green genera at Harper Bridge (site 20), but the decrease in total genera was probably caused by continued effects of Missoula's WWTP discharge. Numbers of genera again increased at Huson (site 22) below the Stone Container discharge. However, more pollution tolerant genera were found at this site, indicating that the wastewater had an impact on water quality. The number of genera continued to increase between Huson and the Flathead River, with the maximum number found above the Flathead River (site 25) in both years.

Cladophora was the dominant non-diatom genus at nearly all Clark Fork River Sites from Deer Lodge (site 09) downstream, as well as in Warm Spring Creek and the Bitterroot River during both years. Cladophora is a robust filamentous green alga that can tolerate moderate levels of inorganic nutrients but is intolerant of heavy metals pollution. Stigeoclonium, a filamentous green alga that is very tolerant of pollution, was most abundant in Silver Bow Creek and at sites downstream below point sources of nutrients (Missoula WWTP and Stone Container) during both years. Stigeoclonium was also very common at upper Clark Fork River sites in 1989, but rare in 1990. The converse was true for Oedogonium, which was not found at these sites in 1989 but was very common in 1990, suggesting at least a slight improvement in water quality in the upper Clark Fork.

The red alga Audouinella, a form relatively intolerant of pollution, was relatively abundant between Deer Lodge and Missoula (sites 10-15.5), and above the Flathead River (site 25) in both years.

The pollution tolerant blue-green alga Synechocystis was dominant at all Silver Bow Creek sites in both 1989 and 1990. Nostoc and Rivularia were most abundant between Warm Springs Creek and Missoula in both years, again possibly due to a nitrogen deficit in this stream reach and ability of these blue-green genera to fix nitrogen. Rivularia was also found at lower river sites below Huson, but Oscillatoria and Phormidium were the dominant blue-green algae in both 1989 and 1990 at Clark Fork River sites below Missoula.

Diatom Algae

The percent relative abundance (PRA) and other statistics calculated for the diatom associations of the Clark Fork River and tributaries for 1989 and 1990 are presented in tables 4 and 5 respectively.

Species richness data are graphed in Figures 4 and 5. In 1989, the number of species counted ranged from 4 to 38; in 1990 the range was 6 to 40. In general, unpolluted waters in Montana have more than 25 species counted (Bahls, 1979). Species richness is directly proportional to water quality. Species richness was lowest at upper Silver Bow Creek sites and increased with distance downstream to Warm Springs Creek. At sites below Warm Springs Creek, species richness fluctuated but for the most part was more than 25 species.

The number of pollution sensitive diatom species (Lange-Bertalot group 3) counted at each site are graphed in figures 6 and 7. In both 1989 and 1990, the range of pollution sensitive species was from 1 to 21. The number of sensitive diatoms increased with distance below upper Silver Bow Creek; however, this trend was reversed with distance below Missoula.

Shannon diversity values are graphed in Figures 8 and 9. The range of values was from less than 2.00 to over 4.00 in both 1989 and 1990. In general, unpolluted waters in Montana have Shannon diversity values greater than 3.00 (Bahls, 1979). Shannon diversity is directly related to water quality. The majority of Clark Fork River and tributary sites, with the exception of Silver Bow Creek and Mill-Willow Bypass, had Shannon diversity values in excess of 3.00 during both years.

Percent relative abundance (PRA) of the predominant taxon at each of the sites is plotted in Figures 10 and 11. Sites with high PRA of the predominant taxon generally had low species richness and low Shannon diversity values; hence, the PRA of the predominant taxon is inversely proportional to water quality.

The total PRA of diatom species in each of the Lange-Bertalot pollution tolerance groups are shown in Figures 12 and 13. The PRA of the sensitive (group 3) taxa are directly related to water quality (Lange-Bertalot, 1979). The lowest PRA values of group 3 taxa occurred at sites 00 to 10 in 1989 and at sites 00 to 09 in 1990, although values were highly variable.

A general increase in the PRA of group 3 species was seen in 1990 over 1989 at the aforementioned sites (except those on Silver Bow Creek and Mill-Willow Bypass), indicating some improvement in water quality in 1990.

The total PRA of the pollution tolerant diatoms (Lange-Bertalot groups 1 and 2) is shown in Figures 14 and 15. The total PRA of the tolerant taxa is inversely related to water quality. Once again, the poorest water quality is indicated at sites 00 to 10 in 1989, and at sites 00 to 09 in 1990. However, at most of these sites a decrease in total PRA was seen in 1990 compared to 1989.

The PRA of the three dominant pollution tolerant taxa (Lange-Bertalot group 1), Navicula atomus, Navicula minima, and Nitzschia palea at each site is graphed in Figures 16 and 17. N. atomus and N. minima dominated at Silver Bow Creek sites. Both are tolerant of both heavy metals and organic pollution (Bahls, 1989). The highest PRA of N. palea was found in and below ACM Pond 2 discharge and in the Mill-Willow Bypass. This species prefers high nutrient levels but connot tolerate heavy metals (Bahls, 1989).

Achnanthes minutissima is considered to be a pollution sensitive (group 3) diatom by Lange-Bertalot (1979), and was a dominant taxon at several mainstem and tributary sites below Dempsey in both years (Tables 4 and 5). It is paradoxical that A. minutissima was also highly dominant at all Silver Bow Creek sites, especially above the Butte WWTP where it comprised about 50 percent of the diatoms present during both years. This species is apparently tolerant of both the heavy metals and nutrients that precluded nearly all pollution sensitive diatoms from occurring in Silver Bow Creek (Figures 6 and 7). It may be that A. minutissima is sensitive to organic wastes and the extreme oxygen deficits that result from their decay; however, the value of this species as an indicator of water quality in the Clark Fork Basin is questionable at best.

The PRA of the three dominant pollution sensitive taxa (Lange-Bertalot group 3), Cocconeis placentula, Cymbella affinis, and Epithemia sorex at each site is graphed in Figures 18 and 19. These species were dominant below site 10 in 1989, and below site 09 in 1990. However, these species increased somewhat in 1990 over 1989 at sites 04 through 09. C. placentula and E. sorex are epiphytes that live attached to primarily *Cladophora* filaments, and thus were most abundant at sites where *Cladophora* was found. Additionally, *E. sorex* harbors unicellular, nitrogen-fixing blue-green algae within its cell walls (Bahls and Weber, 1988); *E. sorex* was most common at sites where nitrogen was likely limiting, suggesting a symbiotic relationship between *Cladophora*, *E. sorex* and the blue-green algae (Bahls, 1989). Conspicously low species richness and Shannon diversity values seen at site 12 in 1989 and sites 10 and 11 in 1990 (Figures 4, 5, 8 and 9) are the result of very large populations of *E. sorex*, which was the predominant taxon at these locations (Figures 10 and 11). Large populations of *C. affinis* at mainstem Clark Fork River sites 18 through 24 in 1989, and 18 through 27 in 1990 had the same effect. The fact that *E. sorex* and *C. affinis*, both pollution sensitive taxa, are able to do well indicates the the water quality at their respective locations is relatively high; however, the structure of the diatom associations (as determined by species richness, Shannon diversity and PRA predominant taxon) suggests a degree of environmental stress that may have prevented other taxa from competing favorably. In the case of *E. sorex* it was probably a deficiency of available nitrogen that provided a competitive advantage. With *C. affinis* it was likely elevated nutrients from point sources (Missoula WWTP and Stone Container) that permitted it to dominate number in the lower Clark Fork River.

CONCLUSIONS

-- The poorest water quality and greatest use impairment, as indicated by the structure and composition of both the non-diatom and diatom algae, occurred in Silver Bow Creek during both 1989 and 1990.

-- Water quality in the ACM Pond 2 Discharge improved greatly over that seen in Silver Bow Creek in both years; however, the algae indicated considerably less improvement in 1989 than in 1990.

-- Very poor water quality was indicated in the Mill-Willow Bypass during both years, with levels of biological impairment approaching those seen in Silver Bow Creek.

-- The algae in Warm Springs Creek indicated slight-to-moderate impairment of water quality in 1989, with some improvement again noted in 1990.

-- Water quality at the Clark Fork River stations between Warm Springs Creek and the Little Blackfoot River was moderately impaired in 1989 but, with the possible exception of the site at Deer Lodge, improve markedly in 1990.

-- For the Clark Fork River sites at Gold Creek, Bonita and Turah, the algae indicated a slight-to-moderate impairment of water quality with some improvement over upstream sites during both years, but little change between 1989 and 1990.

-- Only slight impairment of water quality in the Blackfoot River was indicated by the diatom algae during both years, with little change between years; however, a decrease in non-diatom genera occurred in 1990, but was probably unrelated to water quality.

-- The Clark Fork River above Missoula had the highest water quality of all mainstem sites during both years, based on the structure and composition of both non-diatom and diatom associations.

-- The structure and composition of algae from the Bitterroot River indicate that water quality was very high during both 1989 and 1990.

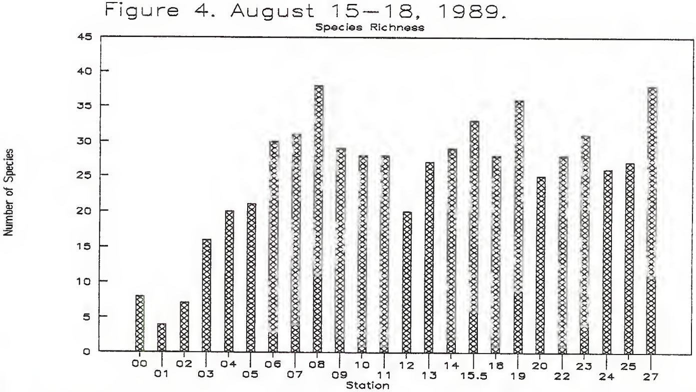
-- The Missoula WWTP discharge had a moderate negative impact on water quality during both years at Shuffield's, and also at Harper Bridge, despite the influx of high-quality Bitterroot River water just upstream of this site.

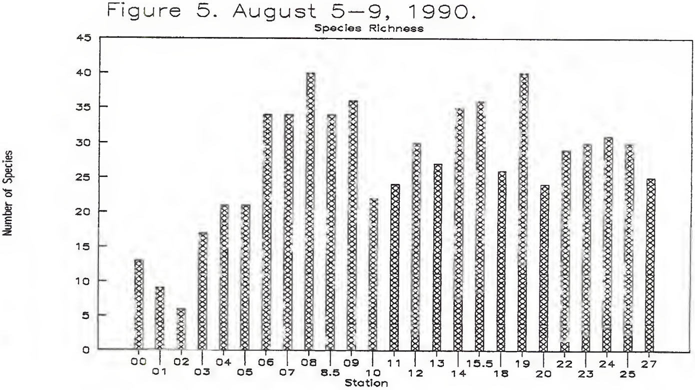
-- The Stone Container wastewater discharge had a slight negative impact on Clark Fork water quality, indicated by changes in the composition (but not the structure) of non-diatom and diatom algae associations during both years.

-- The algae indicated continued slight impairment of water quality in the Clark Fork River from Alberton to the Flathead River, with some improvement at the lower sites during both years.

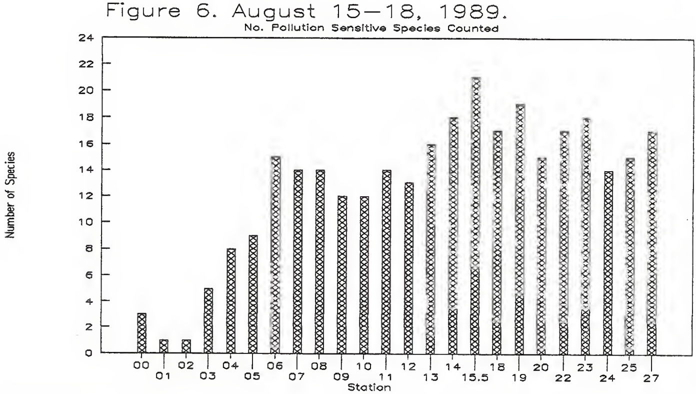
-- Water Quality at the mainstem site below the Flathead River, as indicated by the structure of the algae associations, remained relatively high although the composition of the algae strongly reflected the Flathead River flora.

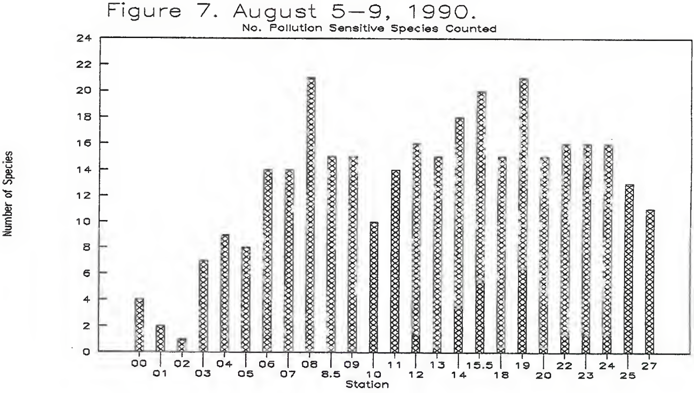
Figures 4 and 5. Diatom species richness (number of species counted) in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.





Figures 6 and 7. Number of pollution sensitive diatom species (Lange–Bertalot group 3) counted in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.





Figures 8 and 9. Shannon diversity values for diatom associations in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.

Figure 8. August 15—18, 1989.

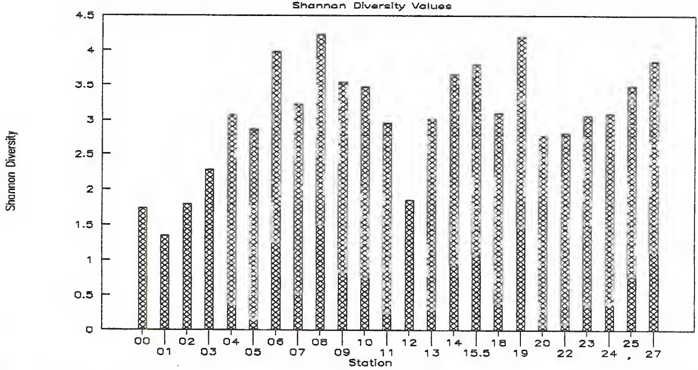
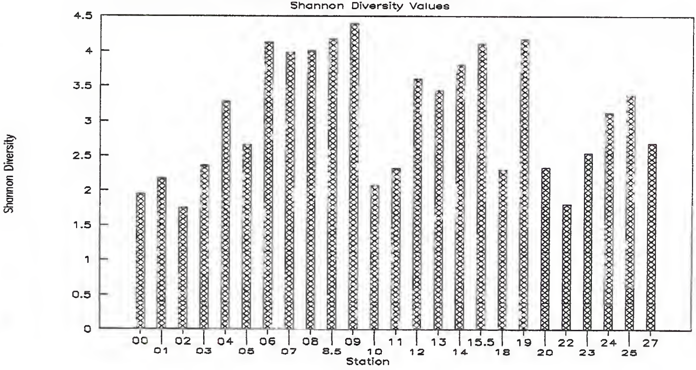
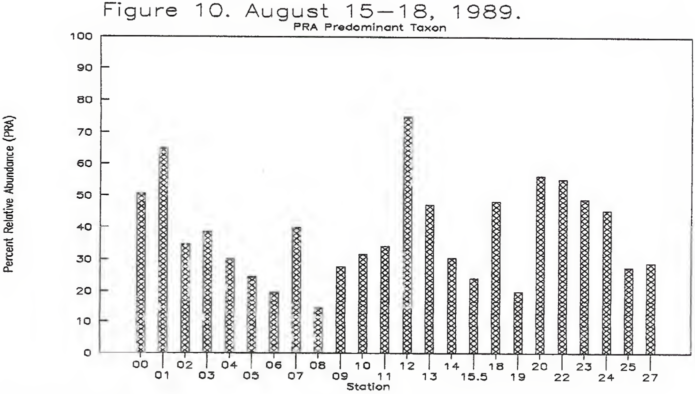
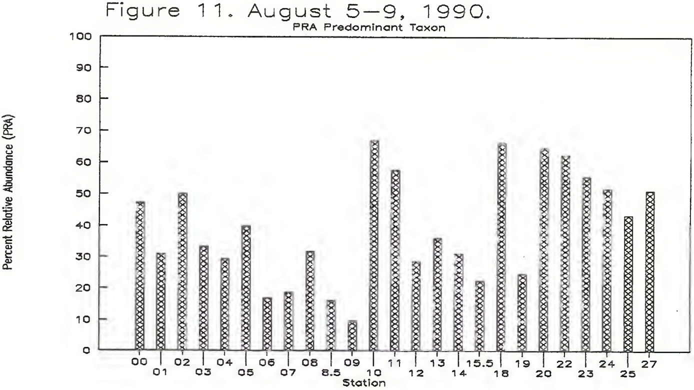


Figure 9. August 5—9, 1990.



Figures 10 and 11. Percent relative abundance (by cell numbers) of the predominant diatom taxon in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.





Figures 12 and 13. Total percent relative abundance (by cell numbers) of diatom species in Lange-Bertalot pollution tolerance groups 1,2 and 3 in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.

Figure 12. August 15–18, 1989.

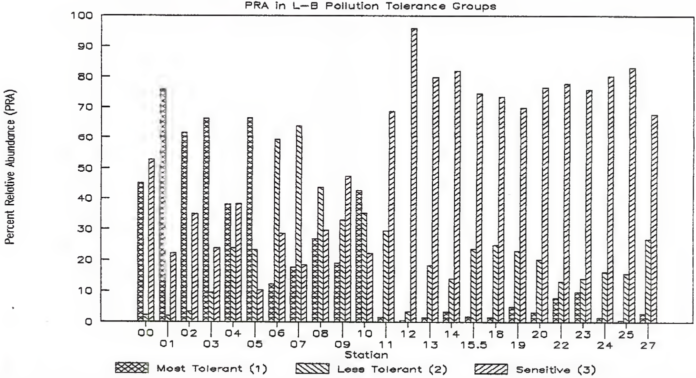
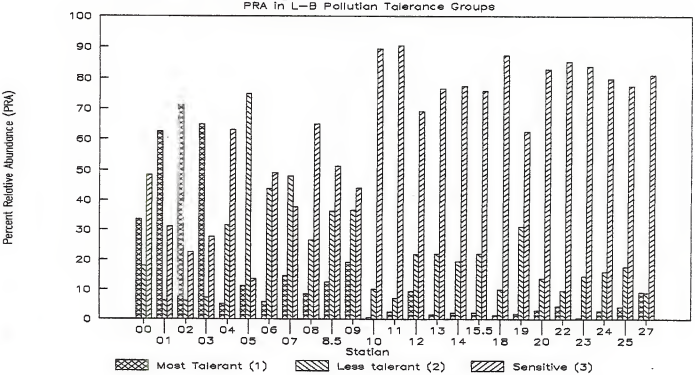


Figure 13. August 5–9, 1990.



Figures 14 and 15. Total percent relative abundance of pollution tolerant diatoms (Lange-Bertalot groups 1 and 2) in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.

Figure 14. August 15–18, 1989.

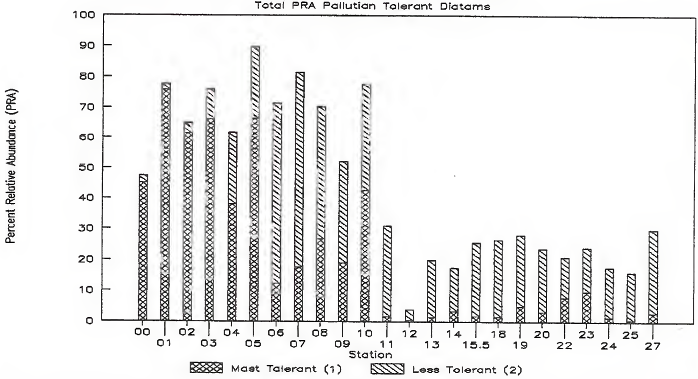
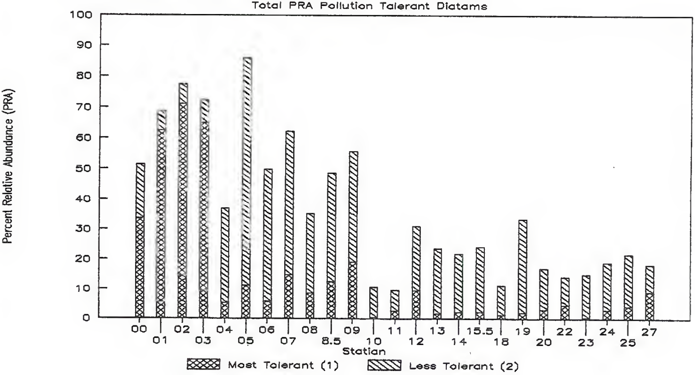
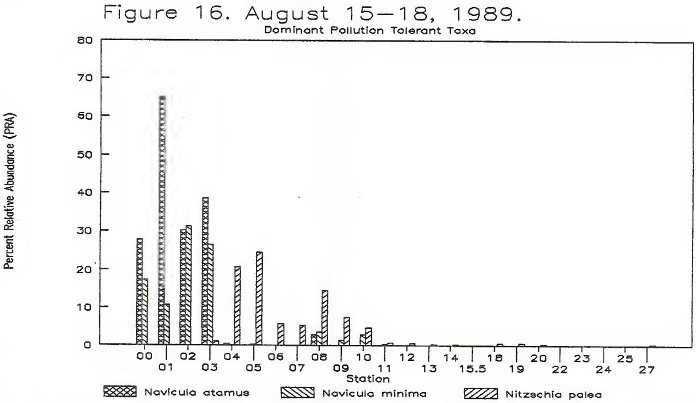
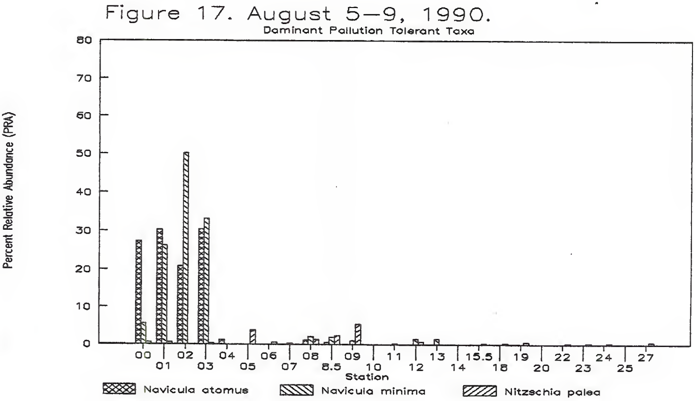


Figure 15. August 5–9, 1990.

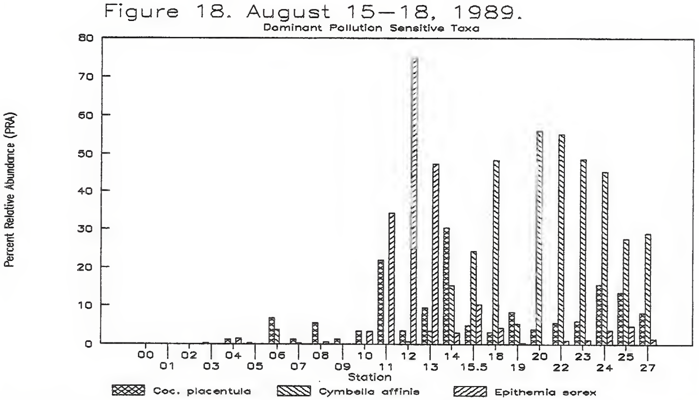


Figures 16 and 17. Percent relative abundance values for three dominant pollution tolerant diatoms (Lange-Bertalot group 1) in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.





Figures 18 and 19. Percent relative abundance values for three dominant pollution sensitive diatoms (Lange–Bertalot group 3) in periphyton samples collected from the Clark Fork River and tributaries during August 1989 and 1990.



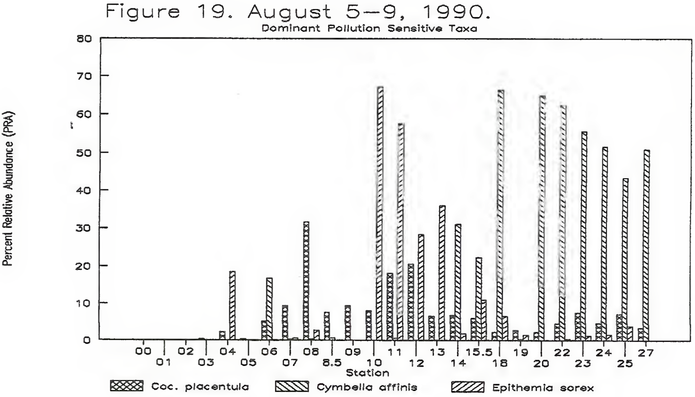


Table 4. Percent relative abundance (by cell numbers) of diatom species in periphyton samples collected from the Clark Fork River and tributaries, August 15–18, 1989. The letter "P" means the species was observed to be present at that station – during a floristic scan – but it was not encountered during the diatom proportional count. PTI= Pollution Tolerance Index (Lange-Bertalot 1979).

SPECIES	PTI[1]	STATION																							
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Achnanthes clevei	3																p		p		p		p		p
A. deflexa	3											p			p	1.7	0.5	0.2	3.6	1.0	0.2	0.5	p	0.2	0.8
A. exigua	3										p														
A. hungarica	2				p																				
A. lanceolata	2	0.5	p	p	0.7		0.5	p	0.2	2.0	1.2	0.8	0.5	p	p	p	0.5	0.2	1.7	0.3	0.2	1.0	0.3	0.2	1.0
A. lapponica	3							p	p																p
A. minutissima	3	50.5	22.3	34.8	22.4	p	4.8	2.4	0.5	1.7	27.8	1.3	0.2		p	7.6	7.3	2.9	4.6	1.8	1.0	2.0	2.0	6.7	11.0
A. peragalli	3																								p
Amphora libyca	3			p																			p		
A. pediculus	3	0.2			p	p				p	p	0.5	p	0.2	1.0	0.2	0.5	0.2	1.2	0.3	0.5	0.5	1.0	p	1.0
A. veneta	1					15.2	p		10.5	p															
Anomoeoneis vitrea	3								p																p
Caloneis bacillum	3			p	0.5				p	0.5	p	p		p					p			p			0.3
Cocconeis diminuta	3																								p
C. pediculus	3							0.7	p	p	p	p	0.2	6.4	3.0	0.9	0.2	1.0	1.2	0.5	0.2	0.5	p	1.2	p
C. placentula	3	p	p	p	0.2	1.3	0.2	6.7	1.4	5.5	1.4	3.5	21.8	3.7	9.4	30.5	4.9	3.2	8.3	4.1	5.6	6.1	15.5	13.4	8.2
Cyclotella comta	4																								0.3
C. meneghiniana	2	p		p	p		4.8	17.8	10.5	8.2	p	0.3	0.2	0.2	0.2		p	0.2	0.2	p	0.2	1.0	2.5	2.0	1.8
C. ocellata	4																								p
C. stelligera	2																								p
Cymatopleura solea	2									p	p						p					p			
Cymbella affinis	3							3.8	0.2		p	p	p	0.7	3.5	15.4	24.3	48.2	5.4	56.1	55.1	48.8	45.3	27.6	29.1
C. caespitosa	3															p	0.2	0.5	p	p	p	p	p		p
C. cistula	3										p								1.2						
C. delicatula	3																								0.3
C. descripta	4							p																	
C. mexicana	3									p						p									
C. microcephala	2							p		p	p					0.2	0.5			p	p				3.6
C. minuta	2			p	0.2	p	4.0	4.1	0.7	7.7	9.2	1.3	p	p	0.2	1.9	0.7	1.0	1.9	1.0	0.7	0.5	0.5	p	0.5
C. prostrata	3															p	p								
C. reichardtii	2									p	p	p								p					0.3
C. silesiaca	2				p			1.2	p	p							p	p	0.5	p	p	0.2	0.3	0.2	p
C. sinuata	3				p		0.2	0.5	0.2	0.2	2.4	2.0	1.7	0.2	0.2	4.5	1.2	0.7	3.2	2.0	3.4	4.4	4.6	5.7	2.6
C. tumida	3																0.2	p	p						
C. turgidula	4																					p			
Denticula kuetzingii	3										0.2														p
Diatoma hiemale	3			p				p									p								
D. tenue	2														p		p	p				p			0.3
D. vulgare	3						0.7	1.0	0.2	p	0.2	0.5	0.5	0.5	5.2	0.5	1.0	0.2	11.9	2.0	1.7	3.7	p	16.7	5.4
Diploneis subovalis	4										p														
Epithemia adnata	3					p						p	0.5	p	1.2	0.7							p		p
E. sorex	3	p				1.5	p		p	0.5	p	3.3	34.2	74.8	47.1	3.1	10.2	4.4	0.2	p	1.0	1.2	3.8	4.7	1.5
E. turgida	3														p	0.9		p						0.5	p
Fragilaria capucina	2		p	p		0.4	10.5	2.2	0.7	p	p			p						p				p	p
F. construens[2]	3	2.0	p	p	0.5	0.9	1.4	1.0	0.9	5.0	2.4	1.0	0.2	2.2	3.0	3.1	8.5	2.4	4.9	2.3	2.7	2.9	2.3	3.5	3.6
F. crotonensis	2				p			0.5					p												
F. vaucheriae	2	p		0.4	1.8	1.1	2.4	0.2	0.7	3.0	2.4	1.0	0.5	0.2	7.7	1.2	4.6	2.4	0.7	0.8	0.7	0.2	0.3	1.2	11.5
Frustulia vulgaris	4																		p						
Gomphoneis eriense	3														p		0.2		0.2	p	p		p		
G. herculeana	4																		p		p				
G. septa	3															p		p		p					
Gomphonema angustatum	3			p				0.5	0.2	p									0.2						
G. angustum	4							p	p						0.2	0.5			1.2		1.2	0.5	2.3	0.7	1.5
G. clavatum	3					2.4	0.7		0.9	0.2									p						
G. clevei	3														0.2	0.7	p	p	p						p
G. gracile	3						p																		
G. hedinii	4																					p			
G. minutum	3					p	0.7							0.5	1.0	3.1	1.0	1.7	20.0	1.5	1.0	0.5	0.5	0.5	2.3
G. olivaceum	3				p		p	1.2	p	0.7	1.2	1.8	0.7	1.0	0.2	0.5	0.7	0.2		p	p	p	0.3	p	0.3

Table 4 (Cont'd)

SPECIES	PTI[1]	STATION																							
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Gomphonema parvulum	1	p	p	p	p	0.2	5.7	0.7	1.4	4.5	2.4	3.0	0.2	p	p	0.5	p	p	0.2	p	p	p	p	p	
G. truncatum	3				p	0.2	p	p	p	p		0.3						p							
Hannaea arcus	3				p				p							p		p							
Hantzschia amphioxys	4			p													p								
Mastogloia smithii	4																								p
Melosira granulata	3											p	p						p				p		
M. varians	2				p		p	19.7	p			0.8		p	p	p	p		p	p	p	p	p		
Meridion circulare	3				p		p		p		p		p					p			p				
Navicula atomus	1	27.8	65.0	30.2	38.6	0.4				2.7								p							
N. bacillum	4																			p					p
N. bryophila	3									p															
N. capitata	2					p							p							p		p			
N. capitatoradiata	2			p				4.8	0.9	0.2		p	0.7		0.2	4.7	6.8	5.4	9.7	4.1	5.1	5.9	3.8	5.2	1.5
N. clementis	4									p															
N. cryptocephala	2						p	p	0.5	p		p			p					p		p			p
N. cryptotenella	2						p	1.4	4.7	2.0	0.5	4.8	4.6	0.2	1.0	2.6	3.6	4.1	1.5	4.1	2.2	0.5	2.0	0.2	1.8
N. decussis	3	p	p	p					p	1.7	0.5	p	0.2	p	p		p	p	0.2	p	0.2	p	p		p
N. exigua	4															p									
N. glomus	4																								p
N. gregaria	2								p		p														
N. halophila	2						p		0.2																
N. ignota	2		p		p				p	p						p			0.2	p	p	p		p	p
N. insociabilis	4	p																							
N. laevissima	3														p								p		
N. lanceolata	2	p							p	p	p		0.2				0.2	p				p			
N. lapidosa	4						p																		
N. libonensis	4			p						p															
N. menisculus	2	p			p			p	p	p	p				p	p			0.2			p	p		p
N. minima	1	17.2	10.7	31.3	26.5		0.2		p	3.5	1.4	2.8	0.2						p				p		
N. minuscula	1	p		p	0.5			0.5	p	0.2	0.7	p													
N. monoculata	4										p														
N. mutica	4																			p					
N. nivalis	4										p														
N. pelliculosa	1					1.5			p																
N. perminuta	4																		1.0	p	p	p	p		
N. placentula	4										p														
N. pseudoventralis	4																								p
N. pupula	2	p			p			p	p	0.5	p	0.3		p	p		0.2		p	p	0.2	0.2	p	p	0.3
N. radiosa	2																p	p							p
N. rotunda	4																								p
N. scutelloides	3																						p		
N. species 2	2				p				0.5	0.2		p	p	p	p	2.1	1.7	1.5	0.7	0.8	p	0.7	1.0	0.2	1.0
N. subhamulata	4									p															
N. tripunctata	3				p			3.4	3.3	p		p	0.7		0.2	1.2	0.2	0.2	p	0.5	1.2	0.2	1.3	p	0.3
N. trivialis	2							p	p	p	p	p	p												
N. tuscula	4			p																					
N. veneta	1			0.2	p	p		0.2	p	0.5	0.2	0.3		p									p		
N. vitabunda	4																								p
Neidium affine	4					p																			
N. amplicatum	4				p																				
N. dubium	3									p		p	p	p											
Nitzschia acicularis	2	p	p	p				p		0.7	p	p	p		p			p					p	0.5	0.3
N. agnita	4															p		p							
N. alpina	3																					0.2			
N. amphibia	2					4.0		p	p	0.2	0.2	0.3						p		p					p
N. bacillum	4									p															
N. capitellata	4										0.7		0.2			p	p	p							
N. communis	1			p	p		p			p		p						p							
N. dissipata	3			p	p		p	1.9	0.5	9.9	1.7	5.0	1.5	1.2	0.7	7.3	11.9	5.6	0.5	2.3	1.7	1.7	1.3	0.2	0.8
N. flexoides	4				p											p		p	p			p			
N. fonticola	3			p		30.1	p	3.1	8.9	0.2	0.5	2.3	5.8	1.0	1.7		0.2	1.5	0.7	1.0	1.0	0.2	0.5	0.2	

Table 4 (Cont'd)

SPECIES	PTI[1]	STATION																					
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Nitzschia frustulum	2									0.5				p	0.7	p						p			
N. gracilis	2								p	0.5	p						p								
N. hantzschiana	3																		1.7		0.7	1.5	1.0	1.0	0.5
N. heufleriana	3							0.2		p							p								
N. hungarica	2																					p			
N. incognita	2					6.8		p	4.0	1.2	0.2		p	p	p				p		p				0.3
N. inconspicua	2	p				3.3	0.2		0.2	2.0	0.5	4.8	7.0	1.0	1.0		1.5	1.9	1.5	1.3	0.5	1.5	2.3	1.7	0.5
N. linearis	3			p	0.2	p	1.2	1.7	0.5	2.7	8.5	0.8	p				p	p			p				
N. paleacea	2		p	p	0.7	7.9	0.7	7.2	40.0	13.9	17.1	20.9	15.3	1.5	7.2	1.2	3.2	8.0	3.9	8.1	3.2	2.4	3.3	4.0	2.0
N. palea	1	p	p	p	0.9	20.7	24.5	5.8	5.4	14.6	7.5	4.8	0.7	0.5	0.2	0.2	p	0.5	0.5	0.3		p	p	p	0.3
N. perminuta	3					1.5	p	0.5	0.2			p	p				0.2	0.2		0.8			p	p	
N. pusilla	1																		p						
N. recta	3							p		p															
N. sigmoidea	3								p				p												
N. supralitorea	2										p													p	
N. valdecostata	4															p									
N. vermicularis	4																								p
Pinnularia microstauron	2								p																
P. viridis	4																		p						
Rhoicosphenia abbreviata	3			p	p	0.2		p	0.5	0.2		p	0.2	3.7	2.0	p	0.2	p	0.5	0.3	0.5	0.5	0.8	0.7	p
Rhopalodia gibba	3					p				0.2		p	p	p											
Stauroneis smithii	4																	p							
Stephanodiscus minutus	4					p																p			
S. subtilis	2																	p						p	
Surirella angusta	2	1.6	2.0	2.6	4.3			p	p	0.5	0.2	p					p								
S. brebissonii	2					p				p	p	p										p			
S. minuta	2	0.2	p	0.4	1.6		p	p	p	0.2	1.2	p	0.2	p			p	p							
Synedra acus	2					0.2	0.2				p	0.3	p	0.2				p	p				p		0.3
S. amphicephala	4				0.5				p																
S. filiformis	3						0.2																		
S. mazamaensis	3														p	0.2	0.5	p	p		p		p		p
S. minuscula	4														p				p						0.5
S. nana	3																					p			p
S. rumpens	3				p	p	p	p	p		0.5					p	p		p	p	p	0.2		p	0.3
S. ulna	1				p		36.1	5.0	0.5	0.7	6.8	31.7	0.5	p	1.2	2.8	1.9	1.2	4.4	3.0	7.8	p	1.3	0.5	2.8
No. Most Tolerant Species	(1)	5	4	7	8	6	6	5	8	9	6	7	4	4	3	3	3	5	5	3	2	3	5	3	2
No. Less Tolerant Species	(2)	10	7	10	15	10	13	21	26	28	25	20	17	15	17	12	20	18	16	19	15	22	15	16	24
No. Sensitive Species	(3)	6	4	12	15	15	18	21	26	25	20	24	23	18	23	25	29	28	29	22	25	23	28	20	32
No. Species PTI Unknown	(4)	1		3	3	2	1	2	2	4	5		1		2	6	1	4	7	3	3	6	2	1	11
PRA Most Tolerant Species	(1)	45.0	75.7	61.7	66.4	38.0	66.5	12.3	17.8	26.8	19.1	42.6	1.7	0.5	1.5	3.5	1.9	1.7	5.1	3.3	7.8	9.8	1.3	0.5	3.1
PRA Less Tolerant Species	(2)	2.3	2.0	3.5	9.4	23.7	23.3	59.1	63.8	43.7	32.9	35.3	29.4	3.4	18.4	13.9	23.6	24.8	22.9	20.3	13.2	14.1	16.3	15.7	26.8
PRA Sensitive Species	(3)	52.7	22.3	34.8	23.7	38.2	10.2	28.6	18.5	29.5	47.3	22.2	68.7	96.1	79.9	82.0	74.5	73.5	69.8	76.4	77.8	75.6	80.2	83.1	67.9
PRA Species PTI Unknown	(4)				0.5						0.7		0.2		0.2	0.5			2.2		1.2	0.5	2.3	0.7	2.3
Total Species		22	15	32	41	33	38	49	62	66	56	51	45	37	45	46	53	55	57	47	45	54	50	40	69
Species Counted		8	4	7	16	20	21	30	31	38	29	28	28	20	27	29	33	28	36	25	28	31	26	27	38
Frustules Counted		442	391	454	438	455	421	416	428	403	414	397	412	408	403	423	411	411	411	394	410	410	393	402	392
Species Diversity (Shannon)		1.73	1.35	1.80	2.28	3.07	2.86	3.97	3.24	4.22	3.55	3.47	2.95	1.86	3.02	3.66	3.80	3.11	4.19	2.76	2.81	3.07	3.10	3.49	3.85

[1] PTI is pollution tolerance index: 1=most tolerant; 2=less tolerant; 3=sensitive. Source: Lange-Bertalot 1979.

[2] Fragilaria construens encompasses specimens identified as F. construens, F. leptostauron and F. pinnata.

Table 5. Percent relative abundance (by cell numbers) of diatom species in periphyton samples collected from the Clark Fork River and tributaries, August 5–9, 1990. The letter "P" means the species was observed to be present at that station – during a floristic scan – but it was not encountered during the diatom proportional count. PTI = pollution tolerance index (Lange-Bertalot 1979).

SPECIES	PTI[1]	STATION																								
		00	01	02	03	04	05	06	07	08	8.5	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Achnanthes clevei	3															0.3			p	p	p	p		p		p
A. deflexa	3							p			p						3.1	0.5	0.2	6.0	0.7	0.3	0.3	p	p	2.0
A. exigua	3																			0.3						
A. hungarica	2											p														
A. lanceolata	2	0.2	0.3	p	p		p	p	0.2	1.2	0.5	1.2	0.3	p	1.2	p	0.5	0.2	p	1.0	p	0.3	0.3	0.2	0.5	0.5
A. minutissima	3	47.2	30.9	22.5	21.1	0.3	3.3	5.2	1.2	3.3	11.7	9.1	p	0.5	2.7	3.3	17.3	8.7	2.4	24.6	0.5	1.5	4.4	5.2	7.7	16.5
A. peragalli	3																					p				
A. pinnata	4																									p
Amphipleura pellucida	4															p				p						
Amphora aequalis	4																	p								
A. dusenii	4				p																					
A. libyca	3																			p		p				
A. pediculus	3				0.3	p		p		0.5	0.5	0.2		p	0.5	8.1	1.5	2.0	p	p	p	0.5	0.8	0.5	0.5	p
A. veneta	1					3.8			0.2	p	p	1.0			p											
Anomoeoneis vitrea	3						p																			p
Caloneis bacillum	3	p		p	0.3		p			0.2		0.2	p		0.7	p										
Cocconeis pediculus	3			p				2.0	5.7	1.9	p	0.2	4.6	2.3	0.7	5.5	p	0.7	0.7		0.2	p			p	p
C. placentula	3	p			0.3	2.3	0.3	5.2	9.5	31.8	7.6	9.4	8.1	18.3	20.7	6.5	6.9	6.0	2.2	2.8	2.2	4.5	7.5	4.7	7.2	3.3
Cyclotella comta	4																									0.3
C. meneghiniana	2	p	p	p	p	0.3	p	3.5	6.5	1.4	2.1	1.2	p	p	p	0.3	p	0.5	p	p	p	p	p	1.0	2.3	0.8
C. ocellata	4																									p
C. striata	4							0.2																		
Cymatopleura solea	2									p		p											p			
Cymbella affinis	3							16.7	0.2	0.2	0.5		p	0.5		p	31.1	22.4	66.3	0.3	64.8	62.4	55.6	51.7	43.5	51.0
C. caespitosa	3													p		p		p	p		p					0.3
C. cesatii	3										p															
C. cistula	3						p													3.0	p	p				
C. descripta	4							p																		
C. elginensis	4																0.5									
C. mesiana	4																			0.5						
C. microcephala	2						0.5	1.0		0.2	0.2	p					5.6	p	p							2.8
C. minuta	2	p	p	p	p	p	28.0	3.5	0.5	1.2	3.8	3.9	0.5	0.5	0.2	1.0	2.6	1.0	0.2	4.0	1.0	0.5	1.0	0.2	0.5	0.5
C. naviculiformis	3							p																		
C. prostrata	3																p		p	p						
C. reichardtii	2							p			p	0.2				0.8	0.3	0.2			p	p	p			
C. silesiaca	2				p		p	0.7	0.2	p		p					0.8	0.2	p	4.0	0.2	0.5	0.5	0.5	0.3	p
C. sinuata	3				p		0.5	1.7	0.5	1.9	1.2	1.0	p	1.0	3.9	1.5	2.6	2.7	0.5	1.5	2.5	3.0	2.9	2.7	3.6	2.0
C. tumida	3																		p	p						
Denticula kuetzingii	3											p														
Diatoma hiemale	3							p										p								
D. tenue	2						0.3																			p
D. vulgare	3				p		p	0.5	1.7	0.2	2.1	0.7	1.0	0.8	1.5	0.8	p	1.2	0.2	0.8	2.7	3.3	1.0	0.7	0.8	
Epithemia adnata	3					p	p					p	p			p	p	0.5		p						p
E. sorex	3			p		18.5			0.5	2.6	p	p	66.9	57.6	28.6	36.0	1.8	10.9	6.6	1.5	p	0.3	1.3	1.5	3.8	p
E. turgida	3						p			0.2							1.8	p	p	0.3				0.5	1.8	0.5
Fragilaria brevistriata	4																	p								
F. capucina	2		2.3	p	0.5	p	39.9	2.7	0.5	0.7		1.2		p	p	p	p				p		p			0.5
F. construens	3	0.7	p	p	5.3	3.8	1.5	8.7	5.0	4.3	5.7	3.0	0.3	p	1.5	6.0	2.3	6.7	1.7	3.0	1.0	2.3	0.8	3.5	5.6	2.5
F. crotonensis	2						4.6	p	0.2		p															p
F. vaucheriae[2]	2	p		p	0.8	2.8	p	2.0	1.7	1.2	0.5	1.5	0.5	0.8	0.7	0.8	2.0	1.5	1.5	1.3	0.7	0.3	1.3	1.0	1.5	2.0
F. virescens	4	p														p										
Gomphoneis eriense	3			p										p			0.5	p	p	0.8	0.2	p				
G. herculeana	3																			p						
G. septa	3																		p							
Gomphonema angustatum	3	p								p	1.2				p		p	0.2			p	p				
G. angustum	4							1.0	p		0.2					p	0.3	0.2	1.5	2.5	0.5	0.8	0.5	0.7	1.3	1.0
G. clavatum	3					0.5	p		2.0					p												
G. clevei	3															p	0.8	p	p	0.3			p		p	
G. minutum	3						p	p	0.2			0.5	0.5	0.3	1.7	1.0	2.0	2.5	1.0	4.0	1.2	0.8	1.3	2.2	1.3	0.8

Table 5. (Cont'd)

SPECIES	PTI[1]	STATION																								
		00	01	02	03	04	05	06	07	08	8.5	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Gomphonema olivaceum	3				0.3			0.2	p	2.8	10.2	1.2	3.1	0.3	1.5	1.3	0.5	1.2	0.5	p	0.2	0.5	0.3	0.2	p	p
G. parvulum	1	0.2	5.6	0.3	0.3	0.3	0.5	0.2	0.5	1.7	2.1	5.7	0.3	0.3	4.9	p	0.5	p	p	p	p			p		
G. pseudotenellum	4																0.3	p								
G. truncatum	3						p	p	p					p	p		p	p								
Hannaea arcus	3						p	p										p			p	p				
Mastogloia smithii	4							p																		
Melosira granulata	3	p																p		p						
M. varians	2						p	17.0	18.7	p	0.7							0.5		0.8	p	p				
Meridion circulare	3	p			p		p	p		0.9			p		p			p								
Navicula accomoda	4		p																							
N. arvensis	4	0.2	p	p			0.3		p																	
N. atomus	1	27.2	30.4	20.8	30.5	1.3				1.2	0.5	p	p		p	p										
N. bacillum	4																							p		
N. bryophila	3																									p
N. capitata	2																			0.3		p			0.3	
N. capitatoradiata	2							4.2	1.0	p		p	p	p	p	1.8	1.3	2.2	2.0	13.8	2.2	2.3	2.1	3.2	2.8	p
N. clementis	4														p											
N. cryptocephala	2					0.8			0.5		p						p			p						
N. cryptotenella	2			p		1.3		0.7	2.0	5.5	9.0	8.4	2.0	1.0	4.2	3.0	1.5	5.5	3.2	0.5	1.2	1.0	3.6	3.7	2.3	0.3
N. cuspidata	4						p																			
N. decussis	3	0.2	0.3							0.7	0.2	1.5	p	p			p			p	p	p		p		
N. elginensis	4	p									p															
N. exigua	4																	p							p	
N. gallica	4											p														
N. gregaria	2	p					p		p	p		p								p		p				
N. halophilloides	4											p														
N. ignota	2	p						0.2		0.2	p		0.3	p	0.5					p	p		0.3	p	0.3	p
N. lanceolata	2									p	p	0.5		0.5		0.3		0.2	p			p	p		0.3	p
N. libonensis	4						p		p	p	p	p														
N. menisculus	2				p			0.2	p					p						0.3	p	0.3				
N. minima	1	5.5	26.1	50.1	33.2	p	p		0.2	2.1	1.9	1.0		0.3	1.5	1.5									p	
N. minuscula	1				0.8			p			p							p								
N. mutica	4											p													p	p
N. muticopsis	4										p															
N. nivalis	4						p																			
N. perminuta	4																			1.3	p	p	0.3			
N. protracta	4	p																				p				
N. pseudolanceolata	4																			p						
N. pupula	2	p					p	0.5		p	p	p		p	p		p	p		p	p	p	p	p	p	
N. radiosa	2															p										
N. species 2	2				p		p	1.0	p	0.2	0.7	1.0	0.5	p	0.5	0.8	2.0	0.7	1.0	0.5	1.5	0.8	0.8	1.5	1.5	0.3
N. subhamulata	4											p														
N. subminuscula	4														p											
N. tripunctata	3		p					3.5	2.7	0.7			p	1.3		p	1.0	1.0	0.7	1.0	0.7	0.8	1.6	2.5	0.5	0.8
N. trivialis	2								p										p		p					
N. veneta	1	p				p	p				p	0.7														
N. viridula	4																	p								
Neidium ampliatum	4									p																
N. dubium	3									p			p													
Nitzschia acicularis	2	p			p		0.3	0.2		0.2	p	5.2	0.3			p		p					p		1.8	0.5
N. alpina	3										p							1.0	p							
N. amphibia	2		p			1.8		p	0.2		p	0.7	p		0.5						p					
N. bacillum	4																						0.8	0.7		
N. capitellata	4								p	p																
N. communis	1	p	p																							
N. dissipata	3				p	1.0	0.8	1.5	p	5.9	4.5	6.4	1.0	0.5	2.2	1.3	2.8	4.5	2.2	6.5	3.7	1.5	1.6	0.5	p	1.0
N. flexoides	4											0.5														
N. fonticola	3					29.3	p	0.7	5.5	3.6	1.0	p	0.3	0.3	0.5	0.8		1.5	1.5	0.8	1.5	2.0	1.0	2.0	0.3	
N. frustulum	2									0.2							0.3		p	1.0				p	p	
N. gracilis	2									p	p			0.5	p				0.2		p		p			
N. hantzschiana	3			p							p											0.8	2.3	0.7		p
N. heufleriana	3							0.2			p	0.2	p					p	p					p		
N. incognita	2					7.3	p	p		0.7	0.2	p	0.3				0.5		p	p			p	0.2		

Table 5. (Cont'd)

SPECIES	PTI[1]	STATION																								
		00	01	02	03	04	05	06	07	08	8.5	09	10	11	12	13	14	15.5	18	19	20	22	23	24	25	27
Nitzschia inconspicua	2	0.2		p		2.5			0.2	2.1	1.4	2.2	2.3	2.0	5.2	12.3	1.0	7.2	0.2	1.3	p	0.5	3.1	1.5	1.0	p
N. linearis	3	p	p	p	p		1.8	2.5	p	0.7	2.1	9.9		0.5	0.2	0.3				p						
N. paleacea	2			p	0.8	14.0	p	6.0	6.7	11.4	16.2	8.9	3.3	1.8	8.4	1.0	1.0	1.7	1.7	2.5	6.7	3.3	1.6	2.7	1.8	0.8
N. palea	1	0.5	0.5	p	0.3	p	3.8	0.5		1.4	2.4	5.4	p	p	0.7	p		0.2	0.2	0.5	p	0.3	0.3	0.2	p	0.5
N. perminuta	3	p			p	1.3		0.2	0.7	0.2	0.7	p			p		0.8		p	4.0	0.2				0.8	
N. pumila	4										p						p									
N. recta	3																	p		p						
N. sigma	4				p																					
N. sigmoidea	3							p							p											
N. sociabilis	4																p									
N. sublinearis	4					p																				
N. umbonata	4											p														
Opephora ansata	4																			0.3			p			
Pinnularia microstauron	2				p																					
P. subcapitata	4				p																					
Rhoicosphenia abbreviata	3				0.3	6.3		p	2.0	1.7	1.9	0.2	3.6	6.3	1.7	3.8	p	0.7	0.5	0.3	p	1.0	1.0	0.2	p	p
Rhopalodia gibba	3						p			0.5			p	p	0.2					p						
R. gibberula	3							p																		
Stauroneis smithii	4						0.3	p		p																
Stephanodiscus minutus	4								p																	
S. subtilis	2	p																							0.3	
Surirella angusta	2	16.6	3.8	5.6	4.6			p	0.2		p				p				p		p					
S. brebissonii	2		p		p			p			p	p														
S. minuta	2	0.7	p	0.8	0.8		0.3	p	p	p	0.5	0.5			0.2				p			p				
Synedra acus	2					1.3	1.0		8.0	p	0.2	p	p	p						p		p		p		
S. fasciculata	4								p																	
S. filiformis	3						5.1																			
S. mazamaensis	3															p	0.5	0.5	p	0.5	p			p	p	p
S. minuscula	4																		p							p
S. nana	3																									p
S. parasitica	4	p			p			p																		p
S. pulchella	2								p																	
S. rumpens	3	0.2			p	p	0.3				p								p	0.3						
S. ulna	1				p	p	6.9	5.2	13.7	2.1	5.5	5.2	0.3	2.0	2.2	0.3	1.8	2.0	1.0	1.5	3.2	4.3	p	2.7	4.1	8.6
No. Most Tolerant Species	(1)	6	5	4	6	7	5	4	4	6	8	7	4	4	6	5	3	4	3	3	3	2	2	3	3	2
No. Less Tolerant Species	(2)	12	8	10	14	11	18	23	22	24	24	24	14	16	16	14	17	16	18	20	20	19	19	15	17	17
No. Sensitive Species	(3)	11	5	8	14	12	21	25	18	23	23	20	21	22	21	22	25	31	29	34	25	25	17	21	20	23
No. Species PTI Unknown	(4)	5	2	1	4	1	5	6	6	4	5	7	0	0	2	3	5	6	2	6	2	3	4	3	3	7
PRA Most Tolerant Species	(1)	33.5	62.5	71.1	65.0	5.3	11.2	6.0	14.7	8.5	12.4	19.0	0.5	2.5	9.4	1.8	2.3	2.2	1.2	2.0	3.2	4.5	0.3	3.0	4.1	9.1
PRA Less Tolerant Species	(2)	17.8	6.3	6.3	7.4	31.8	74.8	43.6	47.6	26.5	36.2	36.7	10.2	7.1	21.7	21.9	19.4	21.9	10.0	31.2	13.6	9.5	14.5	15.9	17.4	8.9
PRA Sensitive Species	(3)	48.4	31.1	22.5	27.7	63.0	13.5	49.1	37.7	64.9	51.2	43.8	89.3	90.4	69.0	76.3	77.3	75.6	87.3	62.3	82.6	85.2	83.6	79.6	77.2	80.7
PRA Species PTI Unknown	(4)	0.2	0.0	0.0	0.0	0.0	0.5	1.2	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0	1.0	0.2	1.5	4.5	0.5	0.8	1.6	1.5	1.3	1.3
Total Species		34	20	23	38	31	49	58	50	57	60	58	39	42	45	44	50	57	52	63	50	49	42	42	43	49
Species Counted		13	9	6	17	21	21	34	34	40	34	36	22	24	30	27	35	36	26	40	24	29	30	31	30	25
Frustules Counted		415	395	395	394	400	393	401	401	422	420	406	393	394	406	397	392	402	409	398	403	399	385	402	391	394
Species Diversity (Shannon)		1.95	2.17	1.76	2.36	3.29	2.66	4.12	3.99	4.01	4.17	4.38	2.08	2.32	3.60	3.44	3.80	4.11	2.30	4.17	2.33	1.81	2.55	3.12	3.37	2.68

[1] PTI is pollution tolerance index: 1=most tolerant; 2=less tolerant; 3=sensitive. Source:lange-Bertalot 1979.

[2]Fragilaria construens encompasses specimens identified as F. construens, F. leptostauron and F. pinnata.

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